Constructing a 50 W 23 cm power amplifier

Chas Gnaccarini VK3PY

This article describes the construction of an RF power amplifier for the 1296 MHz band. Using a combined pair of Mitsubishi RA18H1213G modules, it can deliver a linear output of over 50 watts and in excess of 60 watts at saturation.

Introduction

Some years ago I constructed a Minikits[1] 1296 MHz transverter. Its power amplifier was the then newly introduced Mitsubishi RA18H1213G MOSFET power module. Mitsubishi rates this module at 18 W output from a 12.5 V DC supply.

To my surprise and delight, the power module easily exceeded its published specifications for gain, output power and efficiency when operating from a 14 V supply. It reliably delivered 25 W and could be driven beyond 30 W.

More recently I got to thinking about higher power on 1296 MHz. One possibility was to combine two of these modules to give twice the RF output.

This is not a new idea. Several such designs exist for the superseded M57762 bipolar transistor power module. Down East Microwave[2] in the USA produces versions with two and four combined RA18H1213G modules claiming 60 W and 120 W output respectively. So the concept was clearly viable.

Combining RF power devices

Combining RF power devices presents several challenges which need to be confronted if the result is going to be an efficient, stable and reliable unit. Ideally, all the following criteria should be met:

a. The RF drive power must be equally distributed to each device.

b. The amplified output of each device must be combined in phase at the output.

c. The combination should present a 50 Ω impedance at its input and be matched to 50 Ω at its output.

d. Little or no power should be lost in the combining networks. This is most important at the output where the power is high and losses cannot be recovered.

e. Each amplifying device should be "isolated" from the other(s) at both input and output. That is, each device should operate entirely independently of the others without inter-acting with them.

Photo 1: Trial assembly of the circuit board on its mounting base.

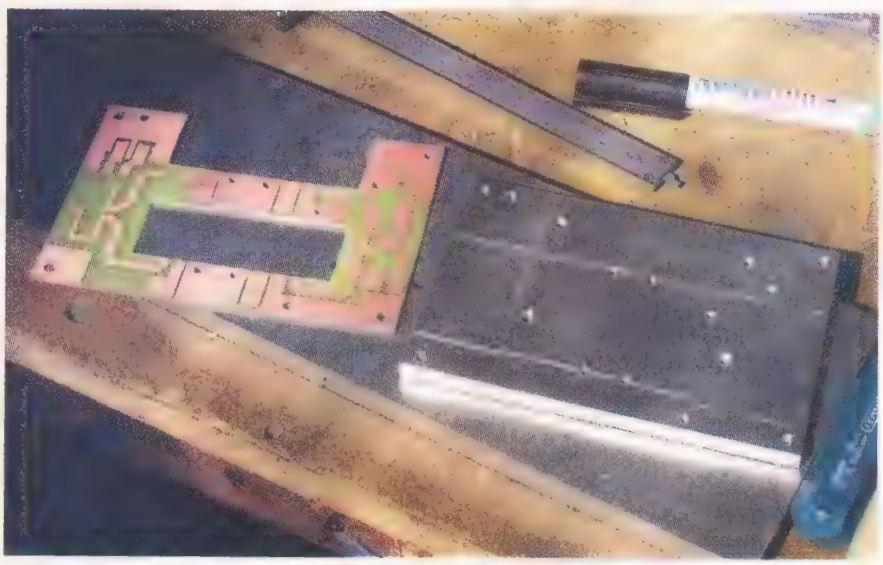

Photo 2: The printed circuit board and heat spreader in preparation for assembly.

f. All the above conditions must be maintained over the entire operating bandwidth.

It seems a daunting task, but at these frequencies we have several options for combining RF power devices. Two common techniques are the quadrature hybrid and the Wilkinson combiner, either of which can be implemented in transmission line form. Both approaches can be made to satisfy all the criteria set out above.

An alternative technique is to simply connect the amplifier inputs and outputs, respectively, in parallel, and transform the resulting nominal 25 Ω impedances to 50 Ω with quarter-wave transformers. This would meet all the criteria except (e). As such, it is a less than ideal approach in that it may invite instability where high-gain amplifying devices are used.

The wavelength, 23 cm, is such that printed-circuit "microstrip" transmission line techniques can be readily employed. The velocity factor of microstrip transmission lines on 1.6 mm (1/16th inch) G10 or FR4 epoxy-fibreglass circuit board is of the order of 0.55. Thus a quarter-wave transformer is only about 30 mm long. The printed circuit approach has the major advantages of reproducibility and simplicity of construction, obviating the need for precisely cutting and terminating miniature transmission lines.

In the end, my choice of combining techniques was to a large extent dictated by the space available for housing the amplifier. I really wanted an amplifier that

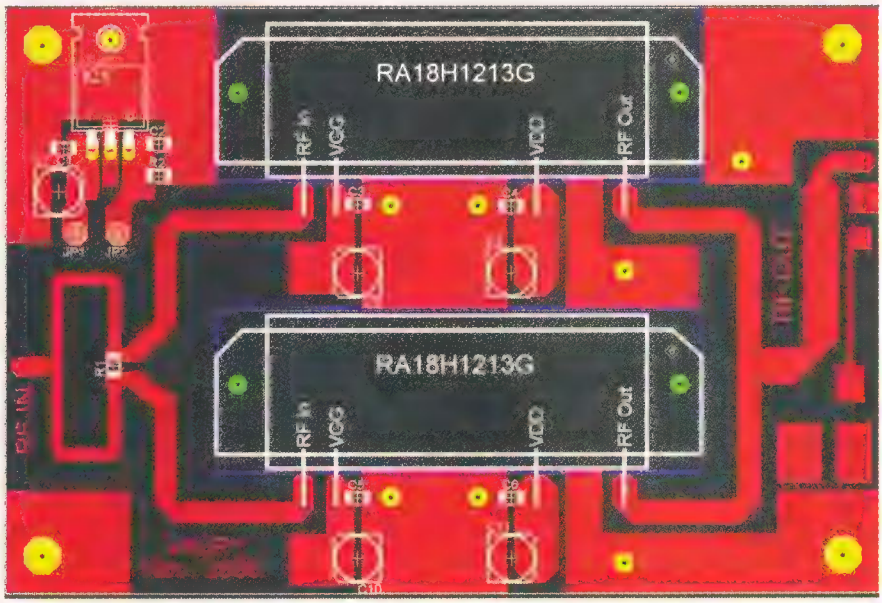

Figure 4: Circuit board and component layout diagram.

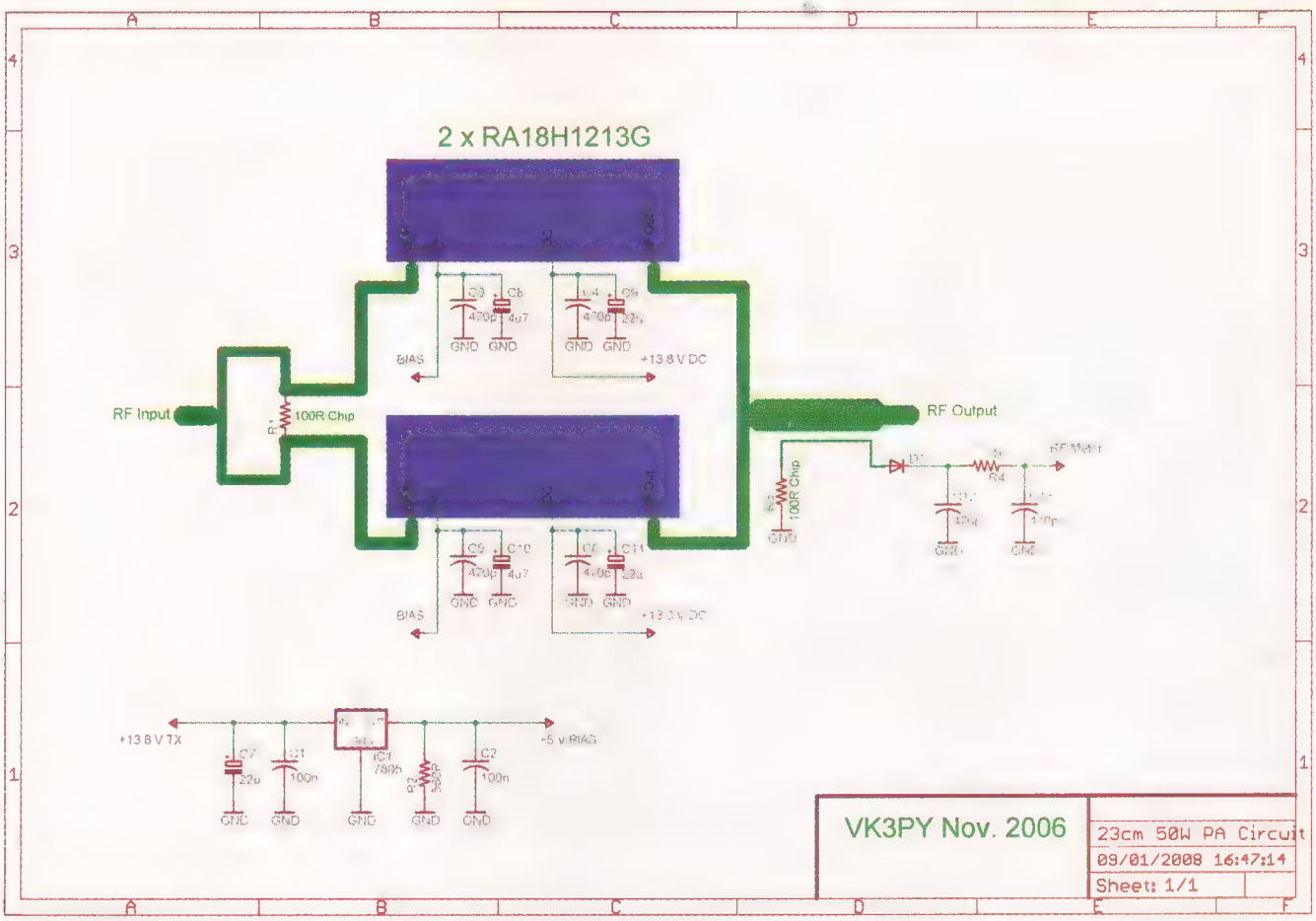

Figure 3: Circuit diagram of the amplifier.

could be retrofitted into my transverter in place of its existing single-module unit.

I had a maximum width constraint of 165 mm which had to include the SMA RF connectors and UT-141 coax radius bends. This meant that printed-circuit quadrature hybrids were out of the question due to the circuit board area they occupy[3].

A Wilkinson hybrid could be used at the input, but as its 70 Ω tracks are only 1.6 mm wide in printed-circuit form, I felt they might be somewhat marginal for the power at the output.

As an experiment, I decided to compromise by using a Wilkinson power divider at the input and just parallel the module outputs with equal-length lines to maintain an in-phase condition. A microstrip quarter-wave transformer would be used to transform the resulting 25 Ω impedance to 50 Ω[4]. At least the inputs would be isolated from each other.

The result was an immediate, resounding success. The amplifier was completely stable and delivered well over 60 W at saturation, limited somewhat by the supply voltage drop in the DC power cable (14 V at idle, dropping to 13.2 V at 60 W). It is very linear to 50 W, reaching its 1-dB compression point at 56 W output, again somewhat compromised by power supply voltage sag in my tests.

Description

The prototype amplifier is constructed on a printed circuit board measuring 120 mm X 80 mm, mounted flush onto a 6 mm thick aluminium base of the same dimensions which is in turn fixed to a heat sink. Alternatively, the amplifier could be built directly onto a heat sink.

Somewhat counter-intuitively, the board is of single-sided construction, the earth back-plane being provided by the mounting base. Careful thought has been given to the positioning of the mounting screws to ensure good earthing of the top side earth areas so the by-pass capacitors provide a low-impedance path back to the power module mounting flange. This is critical for stability.

DC power, bias and RF output metering voltages are brought through 500 pF feed-thru capacitors penetrating the enclosure. The SMA RF in/out sockets are mounted so their centre spigots enter directly through the enclosure walls onto the circuit board at the appropriate points.

The entire unit is firmly mounted onto a heat sink of adequate size. Adequate means big! My heat sink measures 170 X 115 mm with 25 mm deep fins. Even so, with combined power dissipation for the two modules exceeding 100 W at idle and rising to nearly 150 W at maximum output, a cooling fan was required for prolonged transmissions.

Construction

It is assumed that prospective constructors are thoroughly familiar with UHF/microwave construction techniques, or have access to an experienced constructor who can offer guidance.

A suitable signal source and RF power meter are absolutely essential for testing the completed amplifier.

Construction begins with the production of the printed circuit board. This has to be a high-quality product without pin-holes or rough edges on the tracks. The artwork file is in Eagle[5] format and can be downloaded from Amateur Radio section of the WIA website – see this month's issue summary.

After the circuit board has been etched, drill out the mounting screw holes including those for the power modules using a 2 mm or so diameter drill bit. Do not cut out the mounting areas for the power modules just yet. The board will be used as a template for drilling holes in the aluminium mounting base or heat sink.

Place the circuit board, copper side up, onto the mounting base (or heat sink) and

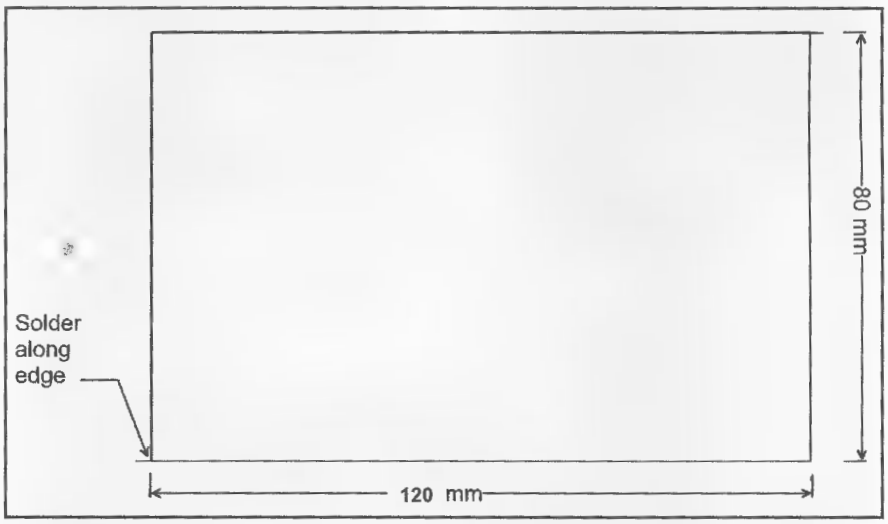

Figure 1: Brass shield enclosure. Note that the two pieces of brass sheet will need to be soldered at diagonally opposite corners.

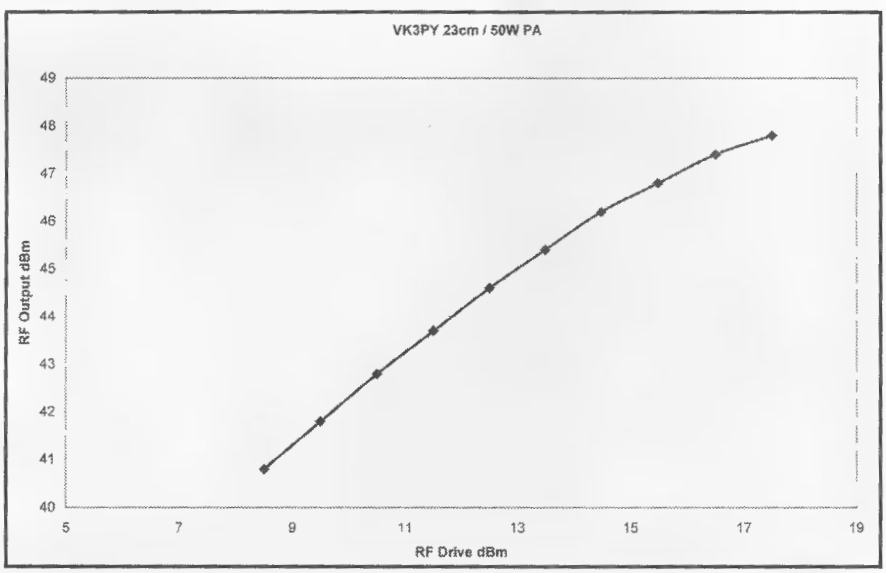

Figure 2: Graph of output power versus input power for the completed amplifier.

firmly tape it in place around it edges. Using the pilot holes in the circuit board as a guide, drill 2 mm holes into the base. Remove the circuit board, then drill out and tap all holes except the four at the corners. I used M4 screws for the power module flanges and M3 to retain the circuit board to the mounting base.

Drill out the four corner holes of the circuit board and mounting base to clear M3 screws. These four corner screws are used for mounting the completed amplifier unit onto a heat sink. De-burr all holes. Photo 1 shows a trial assembly of the circuit board on its mounting base. The location of each screw can be clearly seen.

Drill out the holes in the circuit board to a suitable clearance diameter for the screws and carefully cut out the areas where the power modules are to be mounted. Use photograph 2 as a guide to the general appearance of what you are aiming to achieve.

Using 100-grit wet and dry sandpaper laid on a flat surface, lap both sides of the aluminium mounting base to ensure it is flat. The objective is to ensure you have a very flat surface to achieve good thermal contact between the power module mounting flanges, aluminium base and heat sink.

Cut two strips of 0.5 mm brass sheet, 30 mm wide and bend them into an L-shape as per figure 1. These form the shield enclosure for the amplifier. They are retained with M3 screws drilled and tapped into the edges of the mounting base. Two screws along each edge are sufficient. The two mating corners of the enclosure are soldered along their outer edges.

Take a close look at the power module mounting flanges. They are not flat. The mounting lugs are stepped about 0.2 mm above the rest of the surface, and the surface itself is noticeably bowed inwards. It is imperative that these surfaces be ground flat. One way is to use a belt sander, grinding until the surface is a flat, even, copper appearance.

Alternatively, the surface can be carefully filed flat, then lapped on wet and dry sandpaper in the manner described for the mounting base. Either way, take care not to overheat the modules while doing this. Do not dunk them in water to cool them as they are not hermetically sealed. Instead, use a well-saturated sponge and place the module onto it to cool.

Alternate between the two modules as you work. Note too that the plastic covers will not prevent copper filings from entering the module. **I strongly recommend sealing the edges around the covers with neutral-cure silicone sealant and letting it cure before commencing the grinding operation.**

Lightly tin the areas around the circuit board's mounting holes then fit it to the mounting base and firmly screw it in place. Assemble all peripheral components according to the circuit diagram, paying particular attention to the placement of the ceramic chip by-pass capacitors at the modules' bias and drain supply connections.

These capacitors must be mounted as close to the power module as practicable and such that their earth end is close to the nearest mounting screw. ***Do not fit the power modules yet.***

Fit the brass shield to the assembly. Check that the bottom edges of the shield do not extend below the bottom surface of the mounting base. File them if necessary. Mount the feed-thru capacitors for the bias, DC supply and RF metering connections and the RF connectors.

Before proceeding further, apply + 12 V DC to the bias supply connection and measure the output voltage of the 5 V regulator. Be certain that it is + 5 V DC. If it is not, solve the problem. Failure to do so will surely destroy the power modules if the voltage is any higher.

Having satisfied yourself that the bias voltage is indeed 5 V, you can now proceed to mount the power modules. For each, smear a small quantity of thermal transfer grease on the module's mounting flange ensuring a very light, even coating over its entire surface. Place the module into its position and carefully "work" it in a circular motion to ensure that its surface mates well with that of the mounting base. Finally, screw it in place using appropriate flat washers under each screw head. ***Do not tighten these screws excessively*** as doing so may stress and crack the internal ceramic substrate, rendering the module useless. Cut the module pins to the appropriate length and solder them to the circuit board.

Wire the DC supply and bias connections between the modules and the respective feed-thru capacitors, slipping several mix-43 ferrite beads over each wire. Fit the RF connectors. If required, fit the components associated with the RF output metering. Note these are not indicated on the circuit board layout due to board size limitations imposed by the free version of the Eagle program. However, the circuit diagram should give a good idea of their placement.

This pretty much completes the assembly of the amplifier. Mount the entire assembly onto a heat sink using an even, liberal layer of thermal transfer grease between the mounting base and heat sink. Photo 3 shows the completed amplifier mounted on its heat sink ready for testing.

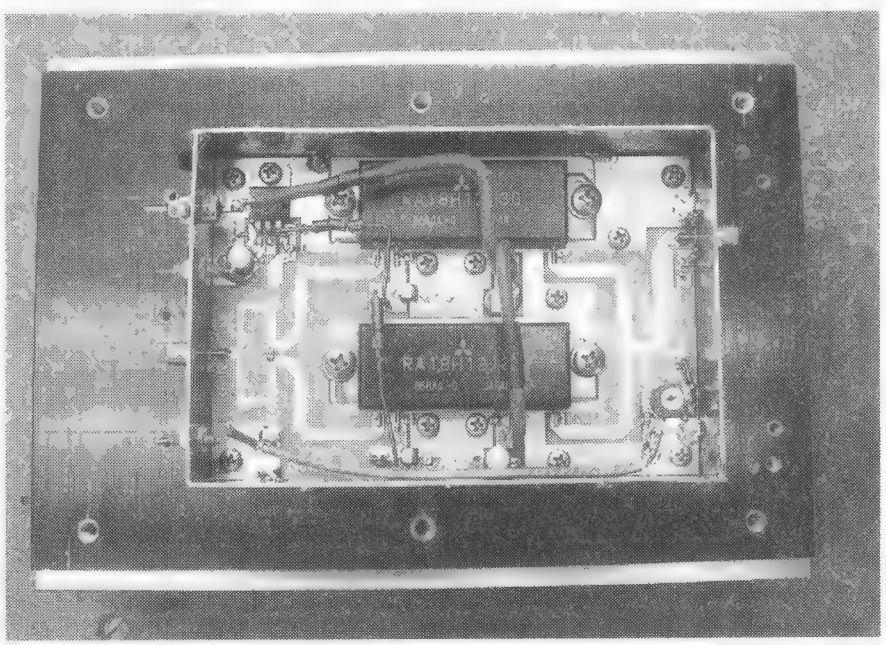

Photo 3: The completed amplifier mounted on its heat sink ready for testing.

Testing

Terminate the amplifier's output into a suitably rated (for power and frequency) RF power meter and dummy load.

Begin by applying 13.8 V DC to the supply voltage connection. The power supply must be capable of delivering in excess of 14 amps. Use a short power cable rated for this current, with a 20 A fuse, and place an ammeter in series. The amplifier should be drawing negligible current at this stage.

Apply 13.8 V DC to the bias input connection and note the idling current. It should be of the order of 7 amps. The power meter should indicate no RF output. Any sign of RF output is an indication of instability and should be checked out (none of the four units constructed to date have misbehaved). If all is in order, disconnect the bias and remove the ammeter from the DC supply line.

Re-connect DC power and bias. Apply a low level (+10 dBm or so) of RF drive and verify you have around 17 W output. While monitoring the output power, increase the drive and verify that you can achieve 50-60 watts. Use the graph of figure 2 as a guide to the drive power requirements.

This completes construction of the amplifier.

My thanks are extended to David VK3QM, Barry VK3BJM and Charlie VK3NX who each constructed copies of this amplifier to verify its reproducibility.

The photographs used in this article were taken by Barry Miller VK3BJM.

Notes

(1) Minikits http://www.minikits.com.au

(2) Down East Microwave http://www.downeastmicrowave.com/

(3) For an example of a 1296 MHz combined module PA using quadrature hybrids see http://www.g3wdg.free-online.co.uk/35wpa.htm

(4) There is some speculation that the output impedance of the RA18H1213G power modules is lower than 50 Ω at high output levels. For this reason the output microstrip lines have been made closer to 40 Ω.

See http://downeastmicrowave.com/PDF/MOSFET%20PA_pdf.PDF

(5) The free version of the Eagle printed circuit board editor may be downloaded from: http://www.cadsoftusa.com/

ar

Parts list:

Most components are available from Minikits: http://www.minikits.com.au

Resistors

R1, R3	100 Ω SMD 1206 or 0805 size
R2	560 Ω SMD 1206 size or ¼ W leaded
R4	1 kΩ SMD 1206 or 0805 size

Capacitors

C1, C2	100 nF either SMD or disc ceramic
C3, C4, C5, C6, C12, C13	470 pF SMD ceramic 0805 size
C7, C8, C9,C10, C11	22 µF Electrolytic, SMD or leaded
500 pF feed-thru capacitors, 3 required	

Miscellaneous

IC1	7805 or 78L05 regulator
D1	1N4148 or similar
RF Modules	2 x Mitsubishi RA18H1213G
SMA Coaxial sockets, 2 required	
mix-43 ferrite beads, 12 required	

Become a radio amateur

Check out the courses on offer from Australia's premier training institution for radio amateurs and hobbyists.

Already licensed?

Upgrade to the Standard licence using our self paced multi-media CD ROM course.

The easiest way to become a licensed radio experimenter.

Discover digital communications, get more power and more bands

Still want more?

Be guided by one of our experienced facilitators using our proven on-line study methods and get your Advanced licence.

Visit

http//www.radioelectronicschool.com

for more information, or email the course manager at

info@radioelectronicschool.net

Telephone 07 5573 2795 12-5PM AEST

Amateur radio – a bridge to careers in radio communications technology

CELEBRATING BEING LICENSED FOR 10 YEARS?

Congratulations!

Now you can join the

Radio Amateurs Old Timers Club of Australia

as an *associate member*

If you have been licensed more than 25 years then you are invited to join as a *full member* of the RAOTC.

In either case a $5.00 joining fee applies. The annual fee is $8.00 or only $15.00 for two years. The Club journal, OTN, is published twice each year and there are monthly news broadcasts. We also guarantee good fellowship.

Write to RAOTC, PO Box 107, Mentone, VIC., 3194

or call Derek VK3XY on 03 9563 6909

or Bill VK3BR on 03 9584 9512.

More details and membership application forms are available from our web site: http//:www.raotc.org.au .